Review Article

An updated review of worldwide levels of docosahexaenoic and arachidonic acid in human breast milk by region

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Abstract

Objective: We aimed to evaluate the DHA and arachidonic acid (AA) levels in human breast milk worldwide by country, region and socio-economic status.
Design: Descriptive review conducted on English publications reporting breast-milk DHA and AA levels.
Setting: We systematically searched and identified eligible literature in PubMed from January 1980 to July 2015. Data on breast-milk DHA and AA levels from women who had given birth to term infants were included.
Subjects: Seventy-eight studies from forty-one countries were included with 4163 breast-milk samples of 3746 individuals.
Results: Worldwide mean levels of DHA and AA in breast milk were 0·37 (SD 0·11) % and 0·55 (SD 0·14) % of total fatty acids, respectively. The breast-milk DHA levels from women with accessibility to marine foods were significantly higher than those from women without accessibility (0·35 (SD 0·20) % *v.* 0·25 (SD 0·14) %, *P* < 0·05). Data from the Asian region showed the highest DHA concentration but much lower AA concentration in breast milk compared with all other regions, independent of accessibility to marine foods. Comparison was made among Canada, Poland and Japan – three typical countries (each with sample size of more than 100 women) from different regions but all with high income and similar accessibility to fish/marine foods.
Conclusions: The current review provides an update on worldwide variation in breast-milk DHA and AA levels and underlines the need for future population- or region-specific investigations.

Human breast milk is universally considered an optimal source of nutrition for term newborns[1]. The concentrations of DHA and arachidonic acid (AA) in breast milk have been extensively studied owing to their fundamental roles in neural and visual development[2,3]. Human milk is being used as a model to define acceptable intakes or recommendations for fatty acids in early life for normal infants[4]. According to recommendations made by the WHO/FAO, term infants should be exclusively breast-fed for the first 6 months of life and regular *n*-3 long-chain PUFA (LCP) should be provided to lactating women to ensure adequate LCP intake for infants[5]. The WHO/FAO recommended LCP intake for infants of 20 mg/kg body weight in 1994[6]; however, no optimal amount of LCP intake for infants was specified thereafter. The International Society for the Study of Fatty Acids and Lipids suggested the AA intake for infants should be above 0·5 % of total

fat in 2008[7]. A Joint WHO/FAO Expert Consultation in the same year recommended that the minimum level of DHA + EPA intake was 0·3 g/d for pregnant or lactating women to ensure normal growth and development of the fetus or infant. AA was not essential for adults if the percentage of energy intake from linoleic acid was more than 2·5 % of total energy, and the upper limit for AA intake was 0·8 g/d for pregnant or lactating women[8]. In 2007, Brenna *et al.* reported that worldwide means of DHA and AA were 0·32 (SD 0·22) % and 0·47 (SD 0·13) % by extensively reviewing peer-reviewed publications[1]. However, it is evident that DHA and AA levels in human breast milk vary by country or population[9]. People residing near the sea may have higher breast-milk DHA levels than those living more inland[10]. This could be partly explained by disparate accessibility to fish or marine foods, a major source of DHA. Socio-economic status also contributes to food accessibility

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and therefore also shapes the dietary pattern of lactating women[11]. Additionally, genetic background has been linked with breast-milk fatty acid composition. For instance, variants of the *FADS* gene cluster were associated with different DHA and AA levels in breast milk at 1 month postpartum[12]. Hence, a worldwide mean of breast-milk fatty acid level may be not applicable for a specific population. In the current comprehensive literature review, we aim to estimate the DHA and AA levels in human breast milk by country, region, as well as country-specific income level, and discuss the possible factors contributing to discrepancies and similarities of data reported.

Methods

Inclusion criteria

A comprehensive literature search was performed in PubMed using 'breast milk' and 'fatty acid' as keywords. Publications in English from January 1980 to July 2015 were considered. Data included breast-milk DHA and AA levels from women who had given birth to term infants, and excluded those who met any of the following conditions: (i) participants under any dietary or lifestyle intervention; (ii) sample size ≤5; (iii) samples obtained from milk bank or pooled samples; or (iv) no information on lactation stage.

Data extraction and quality assessment

The composition of breast milk changes across the lactating period, with the most significant changes occurring in the first two weeks[13]. Therefore, only DHA and AA data obtained >14 d after delivery were included in the present study. In studies reporting data from multiple time points, each time point was included independently and the mean of these data was used. For studies examining the effects of dietary or lifestyle intervention on DHA and AA distribution in breast milk, only the baseline and control groups were included for analysis. In most circumstances, the means of DHA and AA were expressed as a percentage of total fatty acids by weight, while those in other units were excluded. All countries were divided into European region (EUR), African region (AFR), Eastern Mediterranean region (EMR), Asian region (ASR), North American region (NAR), South American region (SAR) and Oceania region (OCR) according to geographic location. The income level of each country was defined according to the World Bank income groups based on per capita Gross Domestic Product: low (≤ $US 1005), lower-middle ($US 1006–3975), higher-middle ($US 3976–12 275) and high (≥ $US 12 276)[14]. Accessibility to fish/marine foods was defined as 'accessible' if: (i) regular fish consumption was clearly stated in the original article; or (ii) sample collection was from island countries or other countries adjacent to lakes, rivers or sea. Otherwise, it was defined as 'not

accessible'. Unweighted means of fatty acid level for a specific country were calculated from single means reported from each study conducted in the country. Subsequently, the calculated mean for each specific country was used to get the unweighted fatty acid level for a specific region. The differences in unweighted means between different countries, regions or income levels were analysed using one-way ANOVA. All analyses were performed using the statistical software package SPSS for Windows version 16.0. Two-tailed *P* value <0·05 was considered significant. Weighted means were calculated by weighting according to the number of samples for each result.

Results

The characteristics of included studies are shown in Table 1. In total, seventy-eight studies from forty-one countries were included with 4163 breast-milk samples of 3746 individuals. Studies included thirty-three from Europe, seven from Africa, five from the Eastern Mediterranean, fourteen from Asia, seventeen from North America, five from South America and five from Australia. Twenty-one countries were classified as high income level, twelve countries as higher-middle income level, six countries as lower-middle income level, and two countries as low income level. Thirty-seven mean levels of DHA were obtained from participants with accessibility to fish or marine foods, while ninety-eight were from those without accessibility. The lactation stage of participants ranged from 2 weeks to 18 months postpartum.

Overall, the unweighted means of DHA and AA in breast milk were 0·37 (SD 0·11) % and 0·55 (SD 0·14) %, respectively. The weighted means of DHA and AA were 0·35 (SD 0·11) % and 0·50 (SD 0·12) %, respectively, which represented a small deviation of less than 0·10 % from our reported value. The country-specific means of DHA and AA are presented in Fig. 1. The mean breast-milk DHA levels ranged from 0·10 % in Sudan to 0·84 % in Malaysia. The breast-milk DHA levels from women with accessibility to marine foods were significantly higher than those from women without accessibility (0·35 (SD 0·20) % *v.* 0·25 (SD 0·14) %, *P* < 0·05; Fig. 2). The levels of AA were relatively constant among regions, with the exception of Iran and Switzerland (beyond 3 SD above the mean value). Breast milk DHA and AA levels are illustrated by region in Fig. 3. Overall, both DHA and AA levels differed regionally. DHA levels were higher for Asian women and lower for Australian and North American women, while AA levels were relatively high for Eastern Mediterranean women and lower for Australian and Asian women. In the subgroup analysis, samples from Asian countries showed the highest DHA levels but much lower AA levels compared with other regions, independent of accessibility to fish/marine foods (Fig. 4). Breast-milk DHA and AA levels are illustrated by World Bank income groups

Table 1 Characteristics of the studies included in the present review

| Author and reference	WHO region*	Country	World Bank income level	Accessibility to fish or marine foods†	No. of samples	Lactation stage	AA (% of total fatty acids)	DHA (% of total fatty acids)
Rocquelin et al.[31]	AFR	Congo	Lower-middle	A	102	5 months	0·44	0·55
Glew et al.[32]		Nigeria	Lower-middle	A	13	1–4 months	0·6	0·3
Ogunleye et al.[33]		Nigeria	Lower-middle	A	20	60–90 d	0·56	0·34
Okolo et al.[34]		Nigeria	Lower-middle	A	15	6–7 months	0·44	0·33
Nyuar et al.[10]		Sudan	Lower-middle	N	32	25–30 d	0·6	0·1
van der Westhuyzen et al.[35]		South Africa	Higher-middle	A	12	6 months	0·6	0·2
				A	18	6 months	1·0	0·1
Luxwolda et al.[19]		Tanzania	Low	A	47	3 months	–	0·68
				A	20	3 months	–	0·96
Marín et al.[36]	SAR	Argentina	Higher-middle	A	21	1–3 months	0·45	0·13
Martin et al.[37]		Bolivia	Lower-middle	A	35	1–3 months	1·06	0·69
Nishimura et al.[38]		Brazil	Higher-middle	N	47	15 weeks	0·48	–
Silva et al.[39]		Brazil	Higher-middle	N	80	4–13 weeks	0·53	0·14
Yuhas et al.[9]		Chile	Higher-middle	A	50	≥1 month	0·42	0·43
Innis et al.[40]	NAR	Canada	High	A	17	1–3 months	0·5	0·2
Ratnayake et al.[41]		Canada	High	A	198	3–4 weeks	0·35	0·14
Yuhas et al.[9]		Canada	High	A	48	≥1 month	0·37	0·17
Krasevec et al.[42]		Cuba	Higher-middle	A	52	2 months	0·67	0·43
Van Beusekom et al.[43]		Dominica	Higher-middle	A	7	20–22 d	0·5	0·4
Yuhas et al.[9]		Mexico	Higher-middle	A	46	≥1 month	0·42	0·26
Rueda et al.[44]		Panama	–	A	8	16–35 d	0·52	0·32
Auestad et al.[45]		USA	High	N	43	4 months	0·51	0·12
Bitman et al.[46]		USA	High	N	6	42 d	0·60	0·23
Bopp et al.[47]		USA	High	A	22	12 months	0·41	0·21
				A	30	12 months	0·38	0·43
Francois et al.[48]		USA	High	A	14	6 months	0·5	0·2
Francois et al.[49]		USA	High	A	7	2–11 months	0·4	0·2
Glew et al.[50]		USA	High	N	19	1–6 months	0·29	0·1
Jensen et al.[51]		USA	High	N	77	4 months	0·44	0·2
Jensen et al.[52]		USA	High	N	6	2 months	0·53	0·19
Martin et al.[37]		USA	High	A	35	1–3 months	0·55	0·16
Putnam et al.[53]		USA	High	A	9	8 weeks	0·6	0·1
Specker et al.[54]		USA	High	A	7	2 months	0·69	0·29
Yuhas et al.[9]		USA	High	A	49	≥1 month	0·45	0·17
Bahrami & Rahimi[55]	EMR	Iran	Higher-middle	N	52	6–19 weeks	1·4	–
Hayat et al.[56]		Kuwait	High	A	19	6–14 weeks	0·54	0·60
Budowski et al.[57]		Israel	High	A	26	6–10 weeks	0·59	0·38
Saphier et al.[58]		Israel	High	A	29	3–4 months	0·44	0·17
Smit et al.[59]		Israel	High	A	10	3–10 months	0·46	0·13
Jørgensen et al.[60]	EUR	Denmark	High	A	39	4 months	0·30	0·35
Jørgensen et al.[61]		Denmark	High	A	16	1 months	0·56	0·49
				A	17	2 months	0·47	0·43
				A	14	4 months	0·44	0·53
Lauritzen et al.[62]		Denmark	High	A	14	1 month	0·6	0·51
Luukkainen et al.[63]		Finland	High	A	9	4 weeks	0·49	0·3
				A	16	12 weeks	0·33	0·18
				A	14	26 weeks	0·28	0·18
Mäkelä et al.[64]		Finland	High	A	51	3 months	0·37	0·22
				A	49	3 months	0·39	0·46

Table 1 *Continued*

| Author and reference	WHO region*	Country	World Bank income level	Accessibility to fish or marine foods†	No. of samples	Lactation stage	AA (% of total fatty acids)	DHA (% of total fatty acids)
Martin *et al.*[65]		France	High	A	24	30 d	0·36	0·24
Maurage *et al.*[66]		France	High	A	15	6 weeks	0·24	0·14
Harzer *et al.*[13]		Germany	High	N	15	3 weeks	0·36	0·15
				N	14	4 weeks	0·39	0·16
				N	15	5 weeks	0·39	0·16
Antonakou *et al.*[20]		Greece	High	A	64	1 months	1·08	0·55
				A	39	3 months	0·89	0·45
				A	24	6 months	0·67	0·52
Decsi *et al.*[67]		Hungary	High	N	15	4 months	0·51	0·18
Kovács *et al.*[68]		Hungary	High	N	10	3 weeks	0·33	0·11
Mihályi *et al.*[69]		Hungary	High	N	61	6 weeks	0·53	0·14
				N	46	6 months	0·46	0·12
Minda *et al.*[70]		Hungary	High	N	18	4 weeks	0·59	0·19
Olafsdottir *et al.*[71]		Iceland	High	A	59	2–4 months	0·32	0·30
Marangoni *et al.*[72]		Italy	High	A	73	3 months	0·50	0·35
Marangoni *et al.*[73]		Italy	High	A	10	1 months	0·64	0·3
				A	10	3 months	0·54	0·25
				A	10	6 months	0·50	0·28
				A	10	9 months	0·51	0·25
				A	10	12 months	0·50	0·34
Huisman *et al.*[74]		Netherlands	High	A	25	42 d	0·34	0·19
				A	99	89 d	0·34	0·19
Helland *et al.*[75]		Norway	High	A	46	1–3 months	0·38	–
				A	36	1–3 months	0·42	0·43
Szlagatys-Sidorkiewicz *et al.*[76]		Poland	High	A	136	17–30 d	0·47	0·33
Rueda *et al.*[44]		Spain	High	A	8	16–35 d	0·69	0·38
Sala-Vila *et al.*[77]		Spain	High	A	10	15–30 d	0·49	0·31
Sala-Vila *et al.*[78]		Spain	High	A	19	15–30 d	0·41	0·18
Sala-Vila *et al.*[79]		Spain	High	A	11	3 months	0·41	0·28
Jørgensen *et al.*[61]		Sweden	High	A	14	4 months	0·44	0·53
				A	17	2 months	0·47	0·43
				A	16	1 month	0·59	0·49
Storck Lindholm *et al.*[80]		Sweden	High	A	19	1 month	0·33	0·37
				A	17	2 months	0·32	0·41
				A	17	1 month	0·37	0·24
				A	14	2 months	0·33	0·22
Xiang *et al.*[81]		Sweden	High	A	19	3 months	0·08	0·12
Xiang *et al.*[82]		Sweden	High	A	19	1 months	0·42	0·28
				A	19	3 months	0·38	0·25
Yu *et al.*[83]		Sweden	High	A	17	1 month	0·46	0·29
				A	17	3 months	0·48	0·24
				A	17	4 months	0·44	0·23
				A	17	6 months	0·34	0·18
Weiss *et al.*[84]		Switzerland	High	N	16	16–20 d	1·79	0·71
				N	6	21–25 d	1·49	0·59
				N	7	26–30 d	1·48	0·56
Samur *et al.*[29]		Turkey	Higher-middle	N	50	12–16 weeks	0·46	0·15
Aydin *et al.*[85]		Turkey	Higher-middle	N	15	28 d	1·81	0·52

Table 1 *Continued*

Author and reference	WHO region*	Country	World Bank income level	Accessibility to fish or marine foods†	No. of samples	Lactation stage	AA (% of total fatty acids)	DHA (% of total fatty acids)
Yuhas et al.[9]		UK	High	A	44	≥ 1 month	0·36	0·24
Glew et al.[86]	ASR	Nepal	Low	N	36	2·9 months	0·43	0·23
Lee et al.[87]		Sri Lanka	Lower-middle	A	47	6–12 weeks	0·39	0·53
				A	44	6–12 weeks	0·36	0·37
				A	45	6–12 weeks	0·39	0·79
Chen et al.[88]		China	Higher-middle	N	33	4 weeks	0·79	0·54
				N	33	6 weeks	0·53	0·35
				A	51	4 weeks	0·56	0·53
				A	51	6 weeks	0·52	0·48
Dodge et al.[89]		China	Higher-middle	N	10	2–18 months	0·52	0·22
				N	10	2–18 months	0·63	0·28
				N	9	2–18 months	0·35	0·15
Huang et al.[21]		China	Higher-middle	A	42	42 d	0·93	0·98
Li et al.[90]		China	Higher-middle	A	25	3 weeks	0·54	0·39
				A	25	3 weeks	0·56	0·42
				N	25	3 weeks	0·63	0·35
				N	11	3 weeks	0·73	0·51
				N	11	3 weeks	0·54	0·29
Peng et al.[91]		China	Higher-middle	A	45	42 d	0·49	0·27
Urwin et al.[22]		China	Higher-middle	N	42	2–4 weeks	0·85	0·53
				A	42	2–4 weeks	0·8	0·53
				N	41	2–4 weeks	0·82	0·35
Wan et al.[92]		China	Higher-middle	N	52	9–12 weeks	0·3	0·19
Xiang et al.[93]		China	Higher-middle	N	18	4 weeks	0·63	0·33
				N	23	12 weeks	0·51	0·18
Yuhas et al.[9]		China	Higher-middle	N	50	1–12 months	0·49	0·35
Ogunleye et al.[33]		Japan	High	A	53	70–100 d	0·36	0·53
Yuhas et al.[9]		Japan	High	A	51	≥ 1 month	0·40	0·99
Kneebone et al.[94]		Malaysia	Higher-middle	A	26	1–6 months	0·47	0·90
				A	10	1–6 months	0·57	0·9
				A	15	1–6 months	0·64	0·71
Yuhas et al.[9]		Philippines	Lower-middle	A	54	≥ 1 month	0·39	0·74
Gibson & Kneebone[95]	OCR	Australia	High	A	61	6 weeks	0·40	0·32
Makrides et al.[96]		Australia	High	A	23	6 weeks	0·45	0·26
				A	23	16 weeks	0·40	0·21
				A	23	30 weeks	0·39	0·19
Makrides et al.[97]		Australia	High	A	23	4 months	0·40	0·21
Stoney et al.[98]		Australia	High	A	36	1 months	0·38	0·26
Yuhas et al.[9]		Australia	High	A	48	≥ 1 month	0·38	0·23

*AFR, African region; SAR, South American region; NAR, North American region; EMR, Eastern Mediterranean region; EUR, European region; ASR, Asian region; OCR, Oceania region.
†A, accessible; N, not accessible.
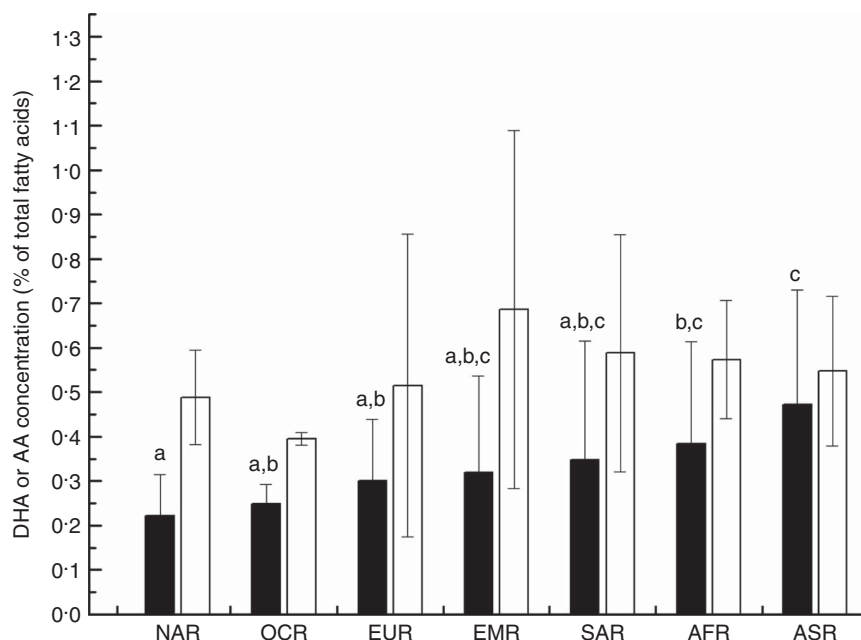
(a)

(b)
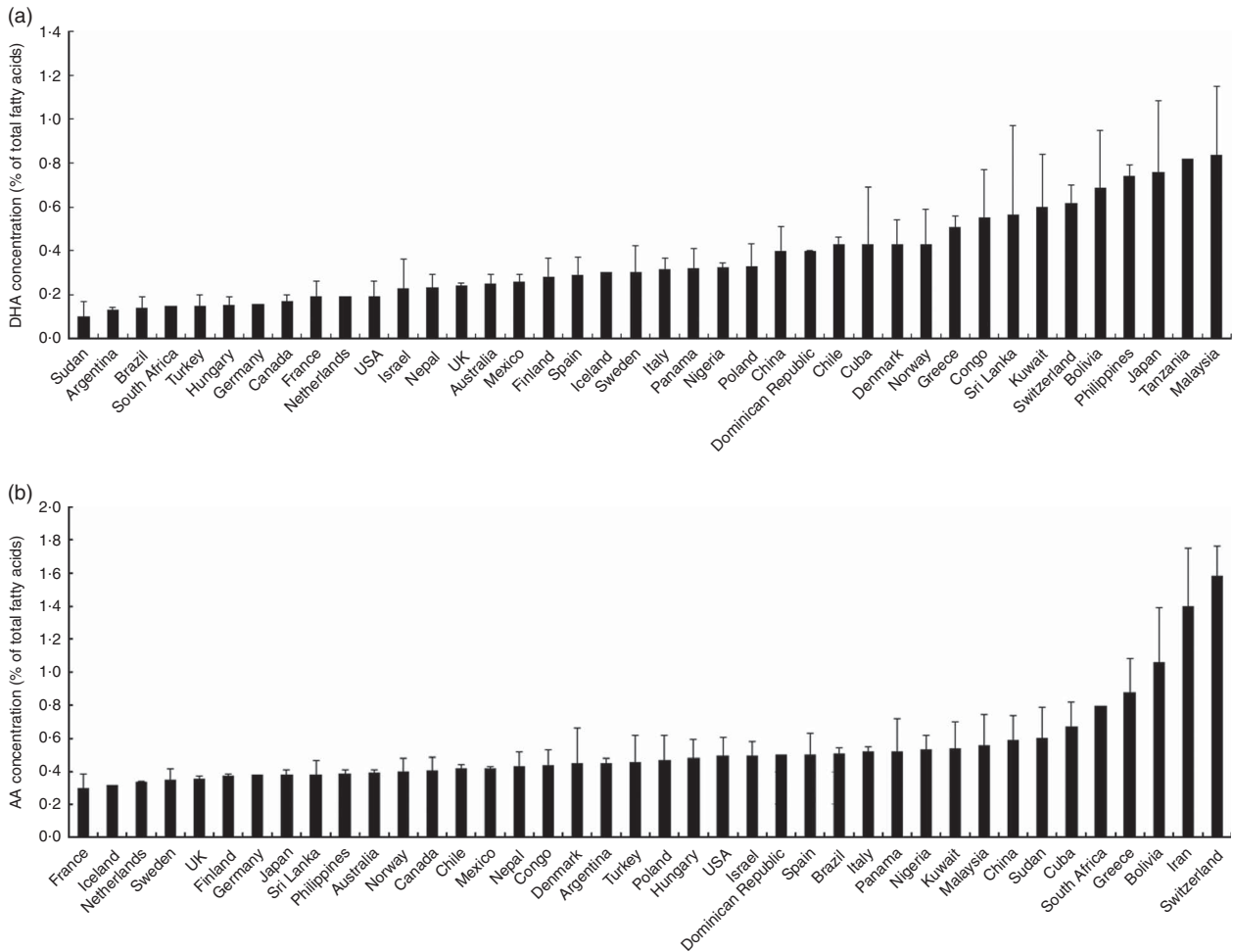
Fig. 1 Country-specific levels of breast-milk DHA (a) and arachidonic acid (AA; b) worldwide. Values are means with their standard deviation represented by vertical bars (seventy-eight studies from forty-one countries were included with 4163 breast-milk samples of 3746 individuals)
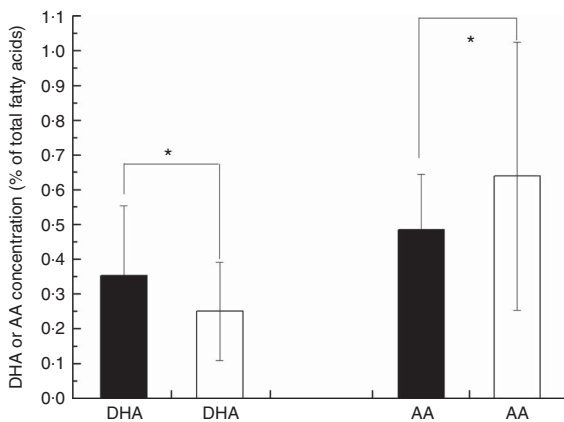
Fig. 2 Worldwide levels of breast-milk DHA and arachidonic acid (AA) by accessibility to marine foods: ■, with accessibility; □, without accessibility. Values are means with their standard deviation represented by vertical bars (seventy-eight studies from forty-one countries were included with 4163 breast-milk samples of 3746 individuals). Mean values were significantly different according to accessibility: *$P < 0.05$

in Fig. 5. Samples from high-income countries exhibited significantly low DHA concentrations in comparison with samples from other countries ($P < 0.05$). However, over 90 % of the data were collected from countries with high or higher-middle income, making a conclusive statement based on income variation difficult. As a previous review on this topic was published in 2007, we compared the collected data published after 2007 with those published before 2007. The means of DHA and AA concentration in breast milk published since 2007 (DHA, 0.42 (SD 0.24) %; AA, 0.71 (SD 0.37) %) were significantly higher ($P < 0.05$) than those reported before 2007 (DHA, 0.32 (SD 0.18) %; AA, 0.47 (SD 0.15) %; Fig. 6). DHA and AA have been most extensively studied in Canada, Poland and Japan (each with samples size of more than 100 women), all three countries from three different regions but with high income and accessibility to fish/marine foods. The breast-milk fatty acid levels, especially DHA level, of women from those countries differed considerably from each other, and confirmed higher DHA level and lower AA level in Asian women's breast milk (Fig. 7).
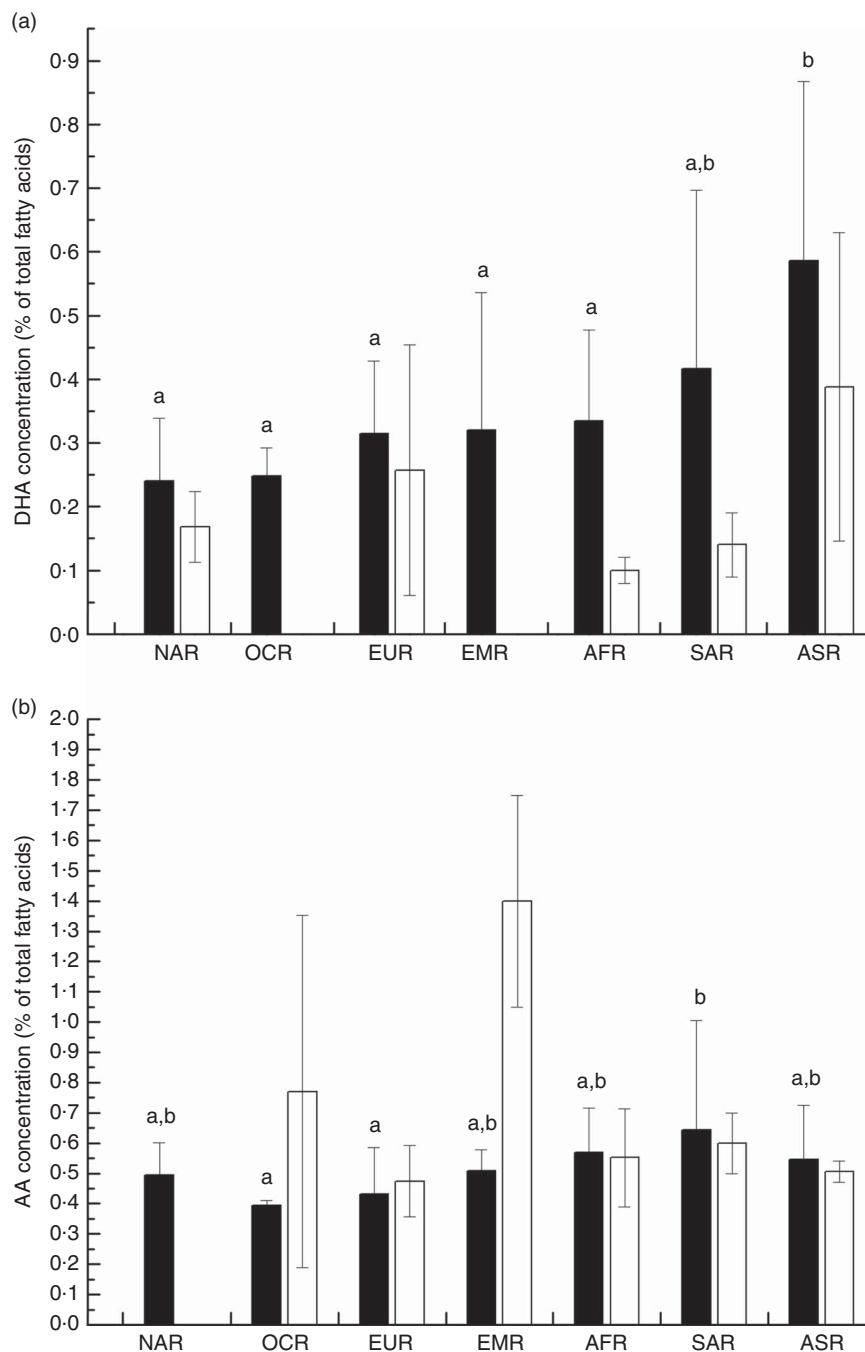
Fig. 3 Worldwide region-specific levels of breast-milk DHA (■) and arachidonic acid (AA; □): NAR, North American region; OCR, Oceania region; EUR, European region; EMR, Eastern Mediterranean region; SAR, South American region; AFR, African region; ASR, Asian region. Values are means with their standard deviation represented by vertical bars (seventy-eight studies from forty-one countries were included with 4163 breast-milk samples of 3746 individuals). [a,b,c]Mean DHA values with unlike superscript letters were significantly different (P < 0.05)

Discussion

Breast-milk composition, despite being one of the most important issues in infant nutrition, has not been detailed by region. Yuhas *et al.* reported the fatty acid composition of breast milk from nine countries located in America, Europe and the Western Pacific region[9], while Brenna *et al.* reported a descriptive meta-analysis for worldwide breast-milk DHA and AA levels[1]. Both of them indicated highly variable breast-milk DHA and AA levels among different countries and that DHA concentration was much more variable than that of AA. The present review describes the variability and levels of breast-milk DHA and AA distributions by region. As global regions are characterized by differences in geographic distribution, population density/ethnicity and socio-economic status[15–17], people from different regions may have varied dietary habits and genetic backgrounds, as well as prevalence of maternal or early-life burden of diseases[17,18]. Therefore, the reasons for the varied breast-milk levels of DHA and AA are multifactorial.

By collecting global data from 1980 to 2015, our analysis found unweighted mean levels of DHA and AA in human breast milk of 0.37 (sd 0.11) % and 0.55 (sd 0.14) %, with minimal difference from weighted means (0.02 % for DHA, 0.05 % for AA). These values are slightly higher than previously reported data by Brenna *et al.* in 2007[1], which estimated unweighted means of 0.32 (sd 0.22) % and 0.47 (sd 0.13) % for DHA and AA, respectively. Of note, we found that the means of DHA and AA levels in

studies published since 2007 (DHA, 0.42 (sd 0.24) %; AA, 0.71 (sd 0.37) %) are significantly higher (P < 0.05) than those reported before 2007 (DHA, 0.32 (sd 0.18) %; AA, 0.47 (sd 0.15) %). Additionally, our review found that women with habitual fish/seafood intake, and/or dwelling near the river or sea, tend to have significantly high DHA levels compared with women without an indicator of good accessibility to fish or marine foods (P < 0.05). Combining the mentioned two findings, the reportedly high consumption of fish or other seafood in Tanzania[19], Greece[20] and China[21,22] after 2007 may help explain the discrepancies. On the other hand, we observed a relatively low level of DHA in the North America region (Fig. 2). This could be partly explained by the low breast-milk DHA levels of included data from inland, such as in the USA, where habitual seafood intake may be more moderate[1]. Therefore, these findings confirm that good accessibility to fish and seafood would likely contribute to breast-milk DHA level. It has been well accepted that maternal dietary habits can influence the nutrient composition of breast milk, especially DHA[9]. For those pregnant or lactating women without accessibility to marine foods, *n*-3 LCP supplementation should be encouraged to ensure normal growth and development of the fetus or infant[8]. Additionally, increased consumption of marine foods in Japanese, Malaysian, Philippine and south-eastern Chinese women who live near rivers or the sea may help explain the high DHA level in the Asian region. However, more studies are needed to explain the low level of DHA in Australia, where marine food consumption is also frequent.

Fig. 4 Subgroup analysis for worldwide region-specific levels of breast-milk DHA (a) and arachidonic acid (AA; b) by accessibility to marine foods: ■, with accessibility; □, without accessibility; NAR, North American region; OCR, Oceania region; EUR, European region; EMR, Eastern Mediterranean region; AFR, African region; SAR, South American region; ASR, Asian region. Values are means with their standard deviation represented by vertical bars (seventy-eight studies from forty-one countries were included with 4163 breast-milk samples of 3746 individuals). [a,b]Mean DHA or AA values with unlike superscript letters were significantly different ($P < 0.05$)

Both DHA and AA can be synthesized endogenously by elongation and desaturation via elongases and desaturases from the dietary precursor α-linolenic acid and linoleic acid, respectively[23]. However, the correlation between dietary sources and breast-milk expression of AA is suggested to be lower than that of DHA[24]. One human study indicated that the conversion rate of α-linolenic acid

to its longer-chain metabolites was nearly ten times higher than that of linoleic acid to AA[25], which may help explain the lower degree of variability of breast-milk AA level among different regions. Moreover, dietary linoleic acid may exert influences on brain function and cognition, not least because of the role it plays as a precursor of AA. Lassek and Gaulin[26] reported a negative relationship in a
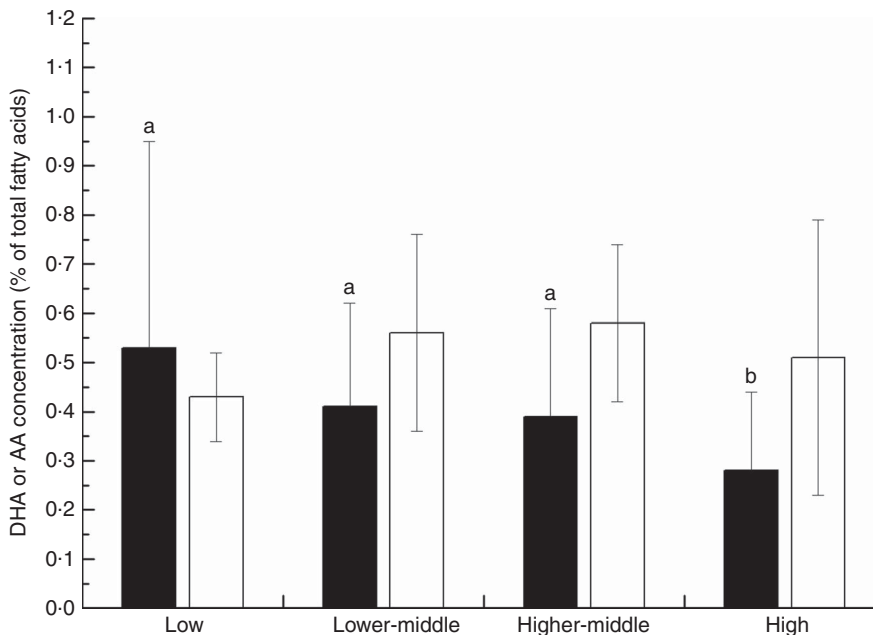
Fig. 5 Worldwide levels of breast-milk DHA (■) and arachidonic acid (AA; □) by World Bank income classification. Values are means with their standard deviation represented by vertical bars (seventy-eight studies from forty-one countries were included with 4163 breast-milk samples of 3746 individuals). [a,b]Mean DHA values with unlike superscript letters were significantly different ($P < 0.05$)
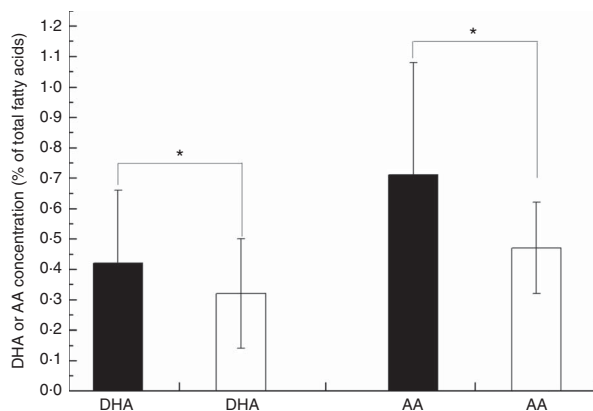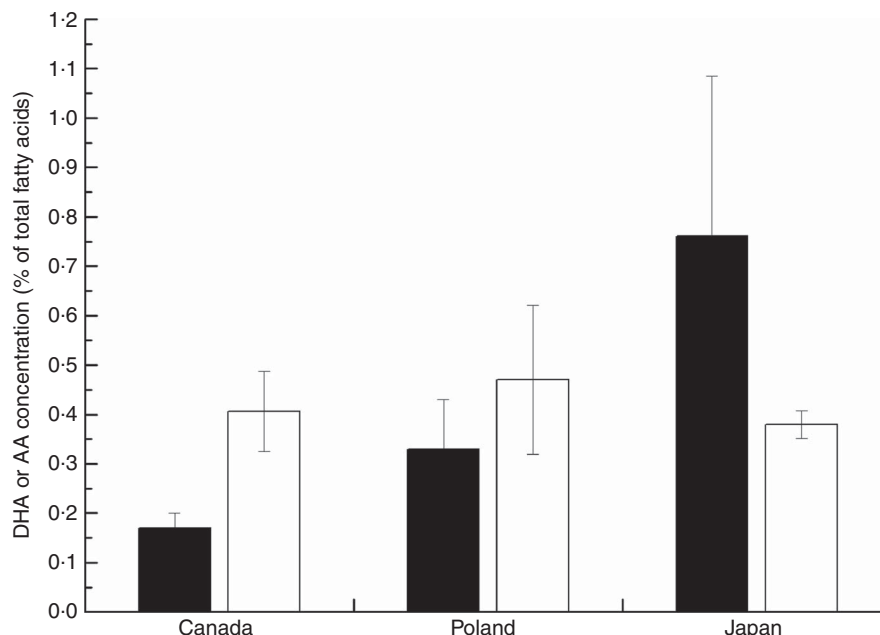

Fig. 6 Worldwide levels of breast-milk DHA and arachidonic acid (AA) reported before (□) and after 2007 (■). Values are means with their standard deviation represented by vertical bars (seventy-eight studies from forty-one countries were included with 4163 breast-milk samples of 3746 individuals). Mean values were significantly different before and after 2007: $*P < 0.05$

compete with DHA for incorporation into plasma phospholipids (immediate source of DHA in breast milk) and inclusion into brain phospholipids[26]. Therefore higher dietary linoleic acid among women may decrease the DHA concentration in breast milk and interfere in the beneficial effects of dietary DHA.

Socio-economic status has been considered a major factor in maternal and infant health[17,27]. However, studies addressing breast-milk composition from lower-income countries are quite limited. For example, less than 10 % of our collected data was from countries with low or lower-middle income due to unavailability of data. Interestingly, we observed that samples from high-income countries exhibited significantly lower DHA level compared with samples from low-income countries. Similarly, Michaelsen et al. found that breast-milk samples from lactating women in low- and middle-income countries generally do not have DHA levels that are considerably lower than those from high-income countries[28]. It should be noted that people from high-income countries tend to consume more processed foods and more trans-fat, which have been suggested to have a disturbing effect on long-chain fatty acid synthesis and metabolism[29].

To control for socio-economic and dietary factors, data from Canada, Poland and Japan were used because these three countries represented different regions and were considered high income and with accessibility to marine foods. The results were consistent with a significantly higher DHA level and lower AA level in Asian countries compared with other regions. Therefore, other possible contributing factors such as the influence of different genetic

sample of twenty-eight countries between breast-milk linoleic acid and test scores in mathematics, reading and science from the Program for International Student Assessment using population-level data, while breast-milk DHA acid in these countries was positively related to the test scores. The opposite relationships of breast-milk linoleic acid and DHA with cognitive performance in the study were attributed to the competition between them. Dietary linoleic acid may not only competitively interfere with the conversion of n-3 fatty acids into DHA, but also

Fig. 7 Breast-milk levels of DHA (■) and arachidonic acid (AA; □) in Japan, Canada and Poland. Values are means with their standard deviation represented by vertical bars (three studies with 263 samples of 263 individuals were included from Canada; one study with 136 samples of 136 individuals was included from Poland; and two studies with 104 samples of 104 individuals were included from Japan)

backgrounds need further investigation. In a study among fifty-four Canadian lactating women, Xie and Innis observed that variations in rs174 553 and rs174 575 within the *FADS* gene cluster were associated with breast-milk levels of AA[12]. Moreover, in a later study among 463 German participants, similar associations were also reported between rs174 547 and rs174 556 within the *FADS* gene cluster and breast-milk AA concentration[30]. The effects of genetics or dietary modification on the composition of breast-milk fatty acids are worth further study.

Several limitations exist in the current study. By only including data of breast milk collected after two weeks postpartum, the DHA and AA levels in colostrum and transitional milk were not examined. Moreover, available data from lower-income countries were quite limited, so the observed DHA level among countries with different income levels may be biased.

Conclusion

Our study reports updated worldwide levels of breast-milk DHA and AA, highlighting relatively high levels of DHA and lower levels of AA in breast milk from women in the Asian region. Novel discrepancies were also confirmed among country-specific and income-stratified DHA and AA levels, which underlines global variations of DHA and AA distributions and the necessity for further population- or country-specific investigations of breast-milk DHA and AA levels.

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